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THE PREDICTION OF NOISE SCATTERED BY A WING/DUCTED FAN CONFIGURATION

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FINAL REPORT
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Final Report

The Prediction of Noise Scattered by a Blended Wing-Body/Ducted Fan Configuration

Introduction

In this proof of concept research, a computational method was developed for predicting the sound field created by the scattering of ducted fan engine noise by a blended wing-body (BWB). It was assumed that all acoustic processes were linear and time harmonic with excitation frequency ω. Inflow effects were neglected and no penetration boundary conditions were applied to the engine nacelle and BWB surfaces.

A scattering approach was adopted in which the total acoustic field is written as the sum of known incident (from the engine duct) and unknown scattered parts. We further assume that the incident field is independent of the scattered field. Application of the above conditions to the equations of linearized acoustics yields the Helmholtz equation (reduced wave equation) for the scattered pressure with Neumann boundary conditions.

Research Approach and Results

An equivalent source method (ESM) was used to solve the classical Helmholtz boundary value problem. The ESM was chosen for its ease of implementation and computational simplicity relative to the more accurate boundary integral or boundary element methods. See references 1-3 and attachments 1-2 of this document for ESM details. The ESM solution methodology development proceeded in four stages.

1) 2-D Scattering: The ESM was applied to scattering of 2-D, point source generated incident sound by simple 2-D elliptical objects. Numerical studies were designed for this simple problem so that pertinent discretization parameters could be identified and applied to the 3-D scattering problem.

2) Simple 3-D Scattering: The 2-D ESM was extended to include the 3-D scattering of point source generated sound by an ellipsoid. Attachment 1 contains sample results and a description of the ESM implementation. All calculations were performed on a Pentium II 350MHz processor with 256Mb RAM. Numerical experimentation showed that meaningful results were obtained for values of the non-dimensional parameter $\alpha < 250$. Where $\alpha = kW$, $k = \omega/c$, c = ambient sound speed, W = largest spatial dimension of scattering body. We estimate that the maximum value of α can be doubled by employing the latest PC technology (as of 11/99) and doubled again with advanced algorithm development.

3) Scattering of Ducted Fan Noise by BWB geometry: Using drawings of the BWB design, the BWB planform shape was approximated by deforming and connecting several ellipsoids. This approach yields an analytical representation of the scatterer that is simple to evaluate. Point source generated sound for

the ESM was replaced by incident sound from a simple ducted fan model. The ducted fan noise prediction program TBIEM3D (reference 4-5) was used to calculate the incident sound. Sample acoustic field calculations for a 4-bladed fan were obtained. Details of the implementation and computational results appear in attachment 2.

4) Comparison with Langley BWB Shielding Experiment: Due to discretization size limitations discussed in stage 2 above, a direct comparison between the ESM and the experiment is impossible. We show that shielding results obtained with the ESM agree qualitatively with the BWB measurements. To simplify calculations we considered a smaller excitation frequency, larger duct radius, and shorter duct length than the experiment. Incident noise was generated by a point monopole placed in the center of the middle duct. Radiation from the outer two ducts was ignored for this set of calculations. By considering a shorter center duct and neglecting the two outer ducts, TBIEM3D computational time is much reduced. These factors do not influence the ESM discretization and could be included at the cost of computational time. See table 1 below for a description of the pertinent operating parameters.

	ESM	**Experiment(*)**
kR	6.0	11.5
W/R	36.7	69.4
L_D/R	2.0	9.74
L/W	0.49	0.51
H/W	0.14	0.084
α = kW	232	798

Table 1: Fundamental Parameters
R = duct radius L_D = center duct length W = BWB wingspan
L = BWB length (tail to nose) H = BWB maximum thickness
(*) Experimental data obtained from Clark and Gerhold

In accordance with the BWB experiment, sound pressure levels were calculated on a plane parallel to the BWB planform and located 0.29 wingspans beneath the duct axis. Computations are performed with and without the BWB presence. For contrast we also compute SPL's on a plane 0.29 wingspans above the BWB. The ESM results are shown in figure 1 and clearly show the scattering effects due to the BWB.

In figure 2, the difference in sound pressure levels between the shielding and no shielding cases are plotted for both the upper and lower observation planes. The results in figure 2a show a shadow region beneath the BWB that is somewhat similar in shape and magnitude to that produced by the experiment.

It is noted that the ESM was not designed to take advantage of the symmetry present in the BWB experiment. Doing so would approximately double the maximum attainable α. Therefore, applying symmetry arguments and the latest PC technology to the ESM would nearly quadruple the maximum α meeting the conditions of the BWB experiment for 1XBPF excitation frequency. For higher harmonics, ESM computational requirements exceed PC capabilities.

Conclusions

Due to its simplicity and ease of implementation, the ESM was shown to be an effective noise prediction tool for acoustic scattering problems. Only simple scattering bodies were considered, but the method is applicable to arbitrary shapes. Comparison with BWB experimental results showed that the ESM calculations are physically correct.

In essence, the ESM is an approximation to boundary integral or boundary element methods. The computational advantages of boundary methods over finite difference and finite element methods are significant and have been addressed in reference 5. Like any solution technique requiring discretization, the ESM is limited to moderate values of excitation frequency and body size.

To expand the range of applicability of the ESM, the consumption of computational resources must be reduced. Theoretical innovation is required for this purpose. For example, the use of multipole expansions combined with boundary integral and advanced grid generation techniques might be used to lower the number of equivalent sources required to produce the desired boundary conditions. Furthermore, ESM algorithms are well suited for multiprocessor computing which would result in a significant decrease in computational time.

References

[1] M. Ochmann 1995 *Acustica 81.* The Source Simulation Technique for Acoustic Radiation Problems, pg. 512-526.

[2] W. Kropp and P.U. Svensson 1995 *Acustica 81.* Application of the Time Domain Formulation of the Method of Equivalent Sources to Radiation and Scattering Problems, pg. 528-543.

[3] F. Holste 1997 *J. of Sound and Vibration 203(4).* An Equivalent Source Method for Calculation of the Sound Radiated from Aircraft Engines, pg. 667-695.

[4] M.H. Dunn 1997 *NASA/CR-97-206232.* TBIEM3D – A Computer Program for Predicting Ducted Fan Engine Noise, Version 1.1.

[5] M. Dunn, J. Tweed, and F. Farassat 1999 *J. of Sound and Vibration 227(5).* The Application of a Boundary Integral Equation Method to the Prediction of Ducted Fan Engine Noise, pg. 1019-1048.

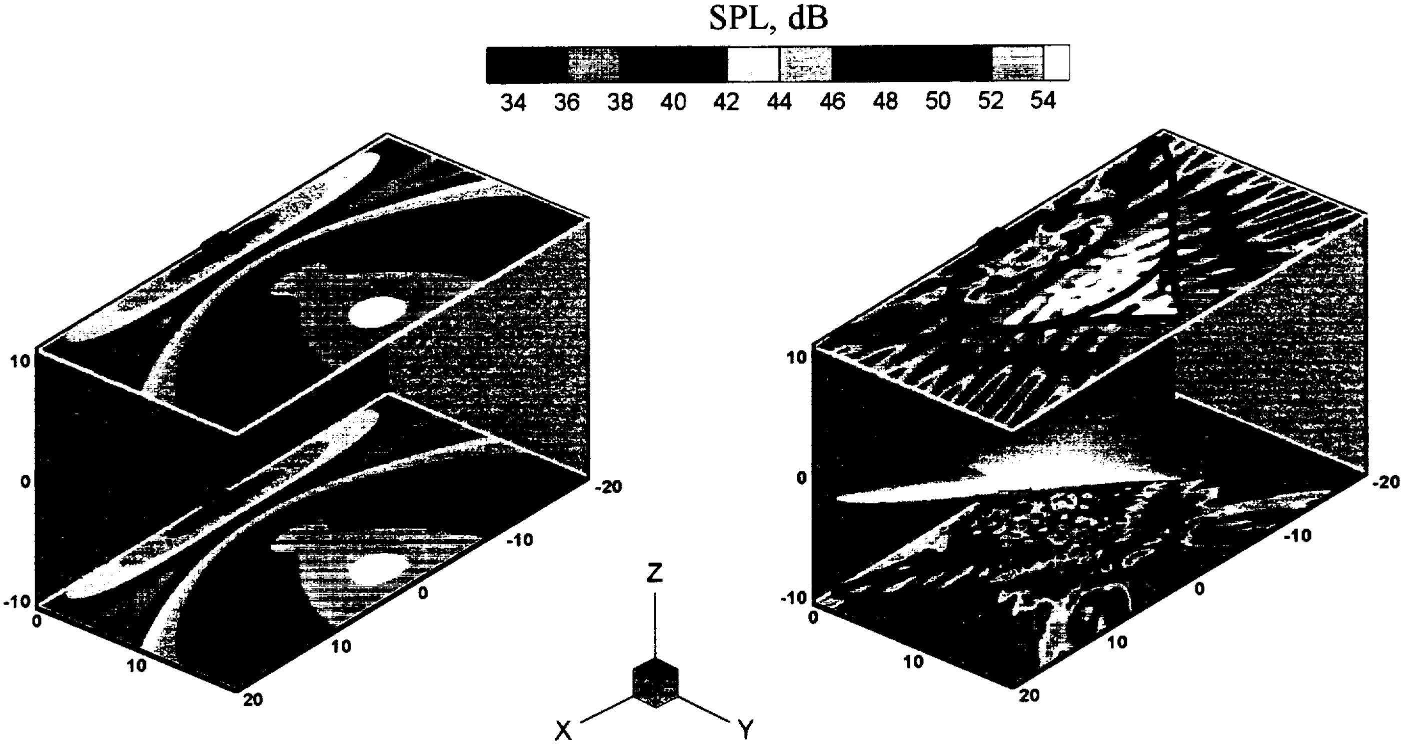


Figure 1: ESM Acoustic Field Calculated on Observation Planes
0.29 Wingspans Above and Below Duct Axis $k = 6.0\ m^{-1}$
a) no shielding b) BWB present

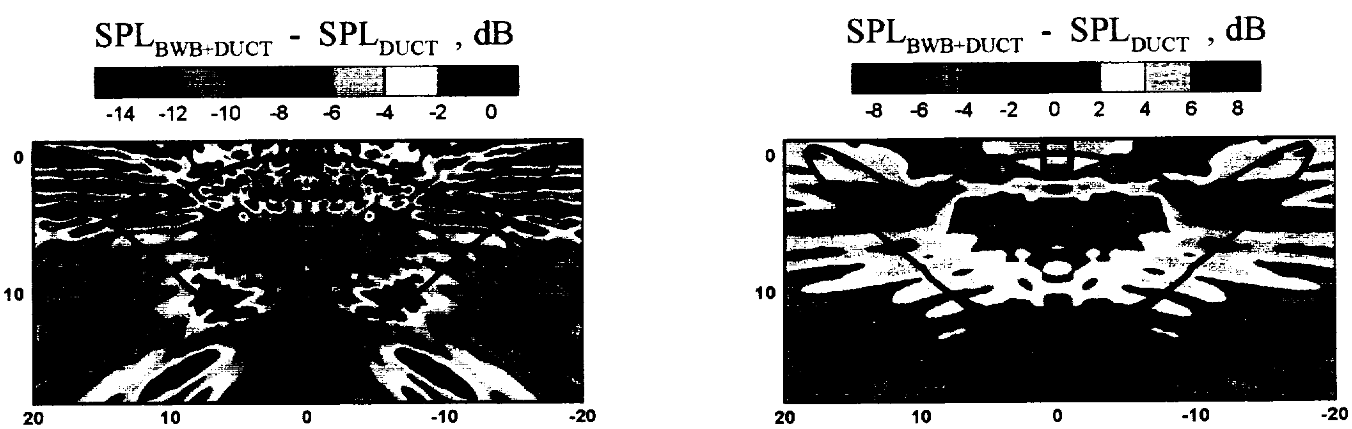
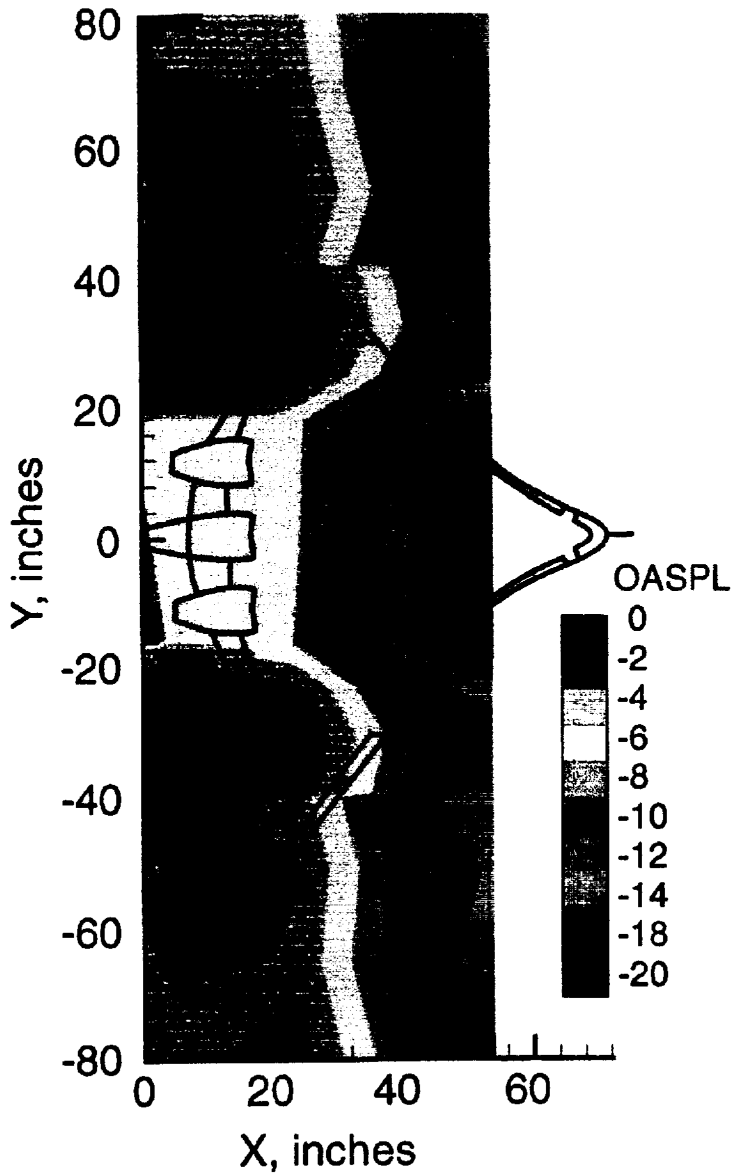


Figure 2: Calculated Noise Difference Due to BWB $k = 6.0\ m^{-1}$
a) lower plane b) upper plane



Calculated overall engine-radiated noise reduction by the Blended Wing Body in flyover.

Figure 3: BWB Experimental Results – Obtained from C. Gerhold

Attachment 1: Report on the Development of a Noise Prediction Method for a Blended Wing/Ducted Fan Configuration

Report on the Development of a Noise Prediction Method for a Blended Wing/Ducted Fan Configuration

Preliminary Results: Application of the Equivalent Source Method to the Calculation of Scattering of Point Source Generated Sound by an Ellipsoid

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Department of Mathematics and Statistics
Old Dominion University

August 30, 1999

Outline

- **Introduction**
- **Problem Description**
- **The Equivalent Source Method (ESM)**
- **3-D Acoustic Field Calculations for Scattering of Incident Sound by an Ellipsoid**
- **Conclusions**
- **Future Effort**

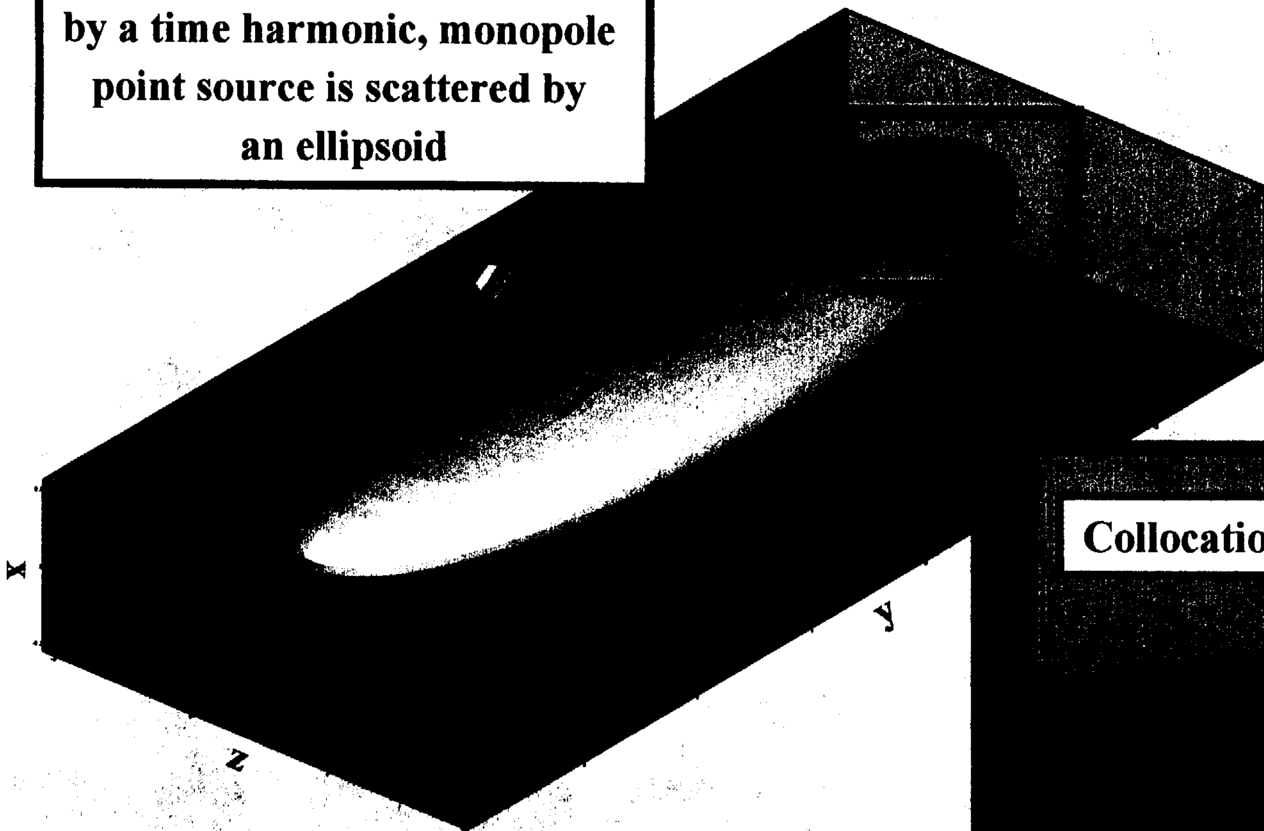
Introduction

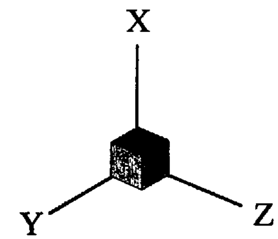
- This report describes recent computational results in which the Equivalent Source Method (ESM) was employed for predicting the 3-D scattering of point source generated incident sound by an acoustically "hard" ellipsoid.

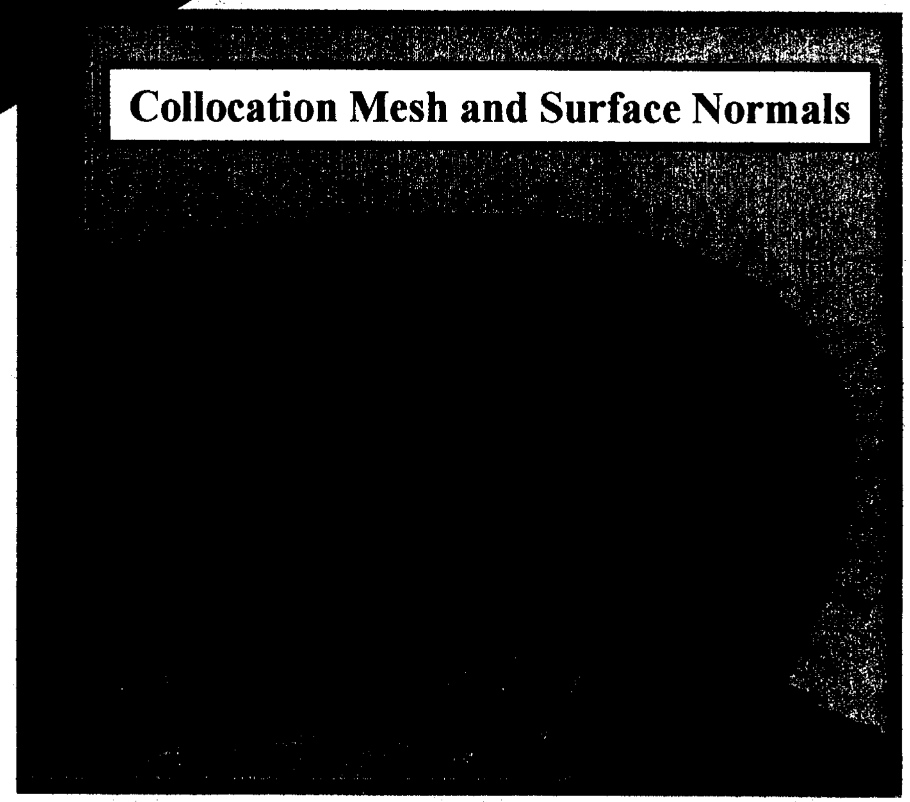
- The effort, sponsored by NASA LaRC, is an essential step in the research project titled "The Prediction of Noise Scattered by a Blended Wing/Ducted Fan Configuration".

System Geometry and Coordinate Definitions

Incident sound generated by a time harmonic, monopole point source is scattered by an ellipsoid







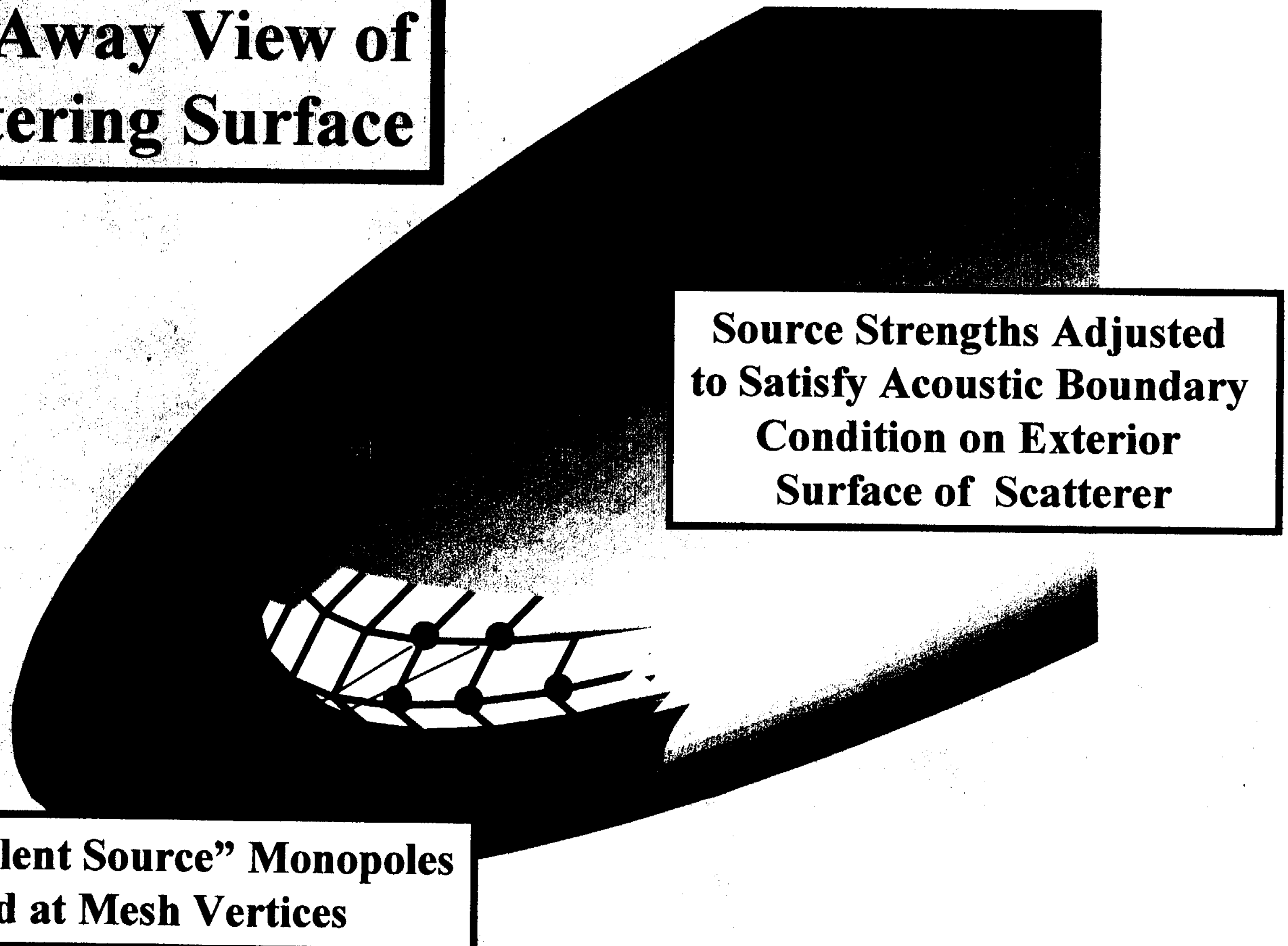
Collocation Mesh and Surface Normals

The Equivalent Source Method

- The ESM replaces a complex surface distribution of acoustic sources with a collection of simple "equivalent sources" placed inside the scatterer. Source strengths are chosen to satisfy the acoustic boundary condition on the scatterer's exterior surface. We consider only the hardwall BC in this work.

- Compared to more conventional prediction methods, such as those that use boundary integrals or boundary elements, the ESM is much simpler to implement and calculate.

Cut-Away View of Scattering Surface



ESM Features

- Acoustic Pressure = Incident Pressure (from Monopole) + Pressure Due to N_s Equivalent Source Monopoles.
  All pressure components are time harmonic with frequency ω.

- Normal derivative of acoustic pressure is evaluated at N_c collocation points on obstacle surface yielding a linear system with N_c equations in N_s unknowns (source strengths).

- The overdetermined linear system ($N_c > N_s$) is solved using least squares methods.

Results

- To demonstrate full 3-D effects and shielding properties of the ellipsoid, results for a single case are shown in which contours of instantaneous acoustic pressure are plotted for various regions of 3-D space.

- Calculations were conducted on a Pentium II, 350 MHz PC with 256 Mb RAM. Computational times vary from 1 to 3 minutes per 10,000 field points depending on the number of source and collocation points.

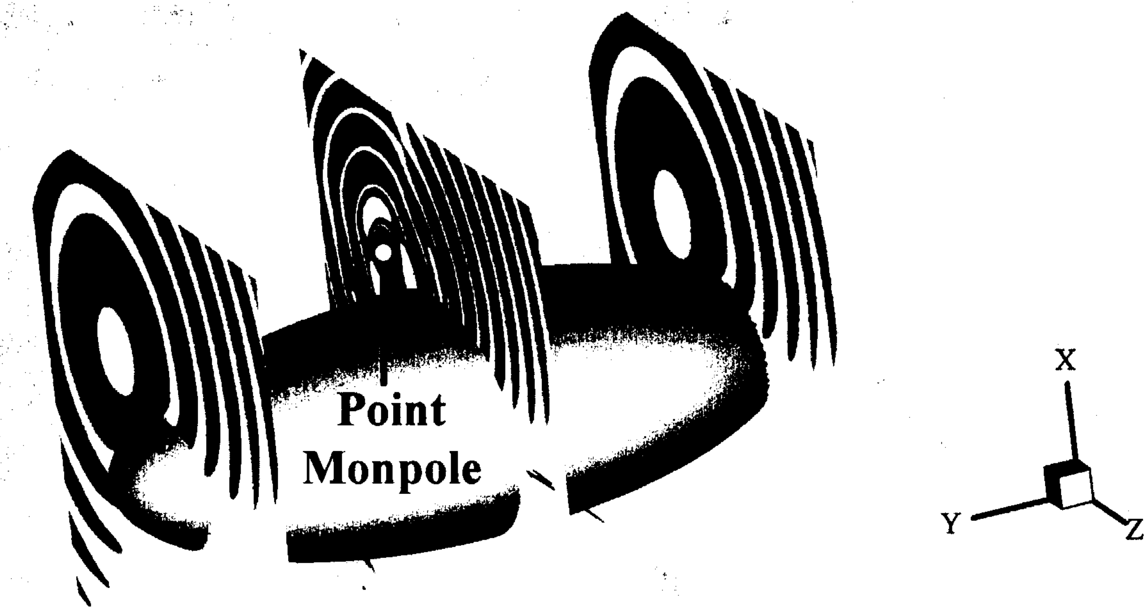
3-D Scattering Results
(x-z slices)

$k = \omega/c$

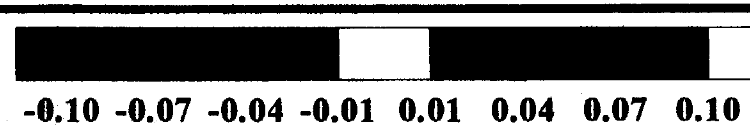
$= 10.0\ m^{-1}$

$N_s = 800$

$N_c = 1400$



Re[Instantaneous Acoustic Pressure]



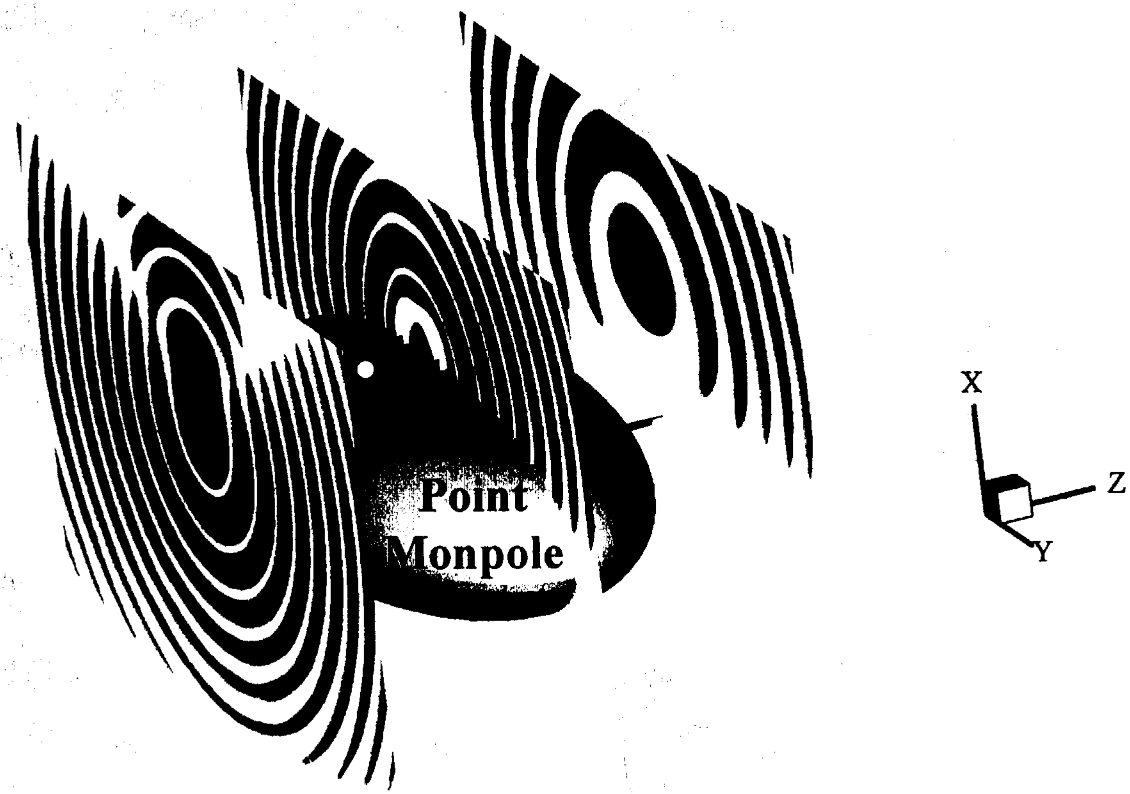
3-D Scattering Results
(x-y slices)

$k = \omega/c$

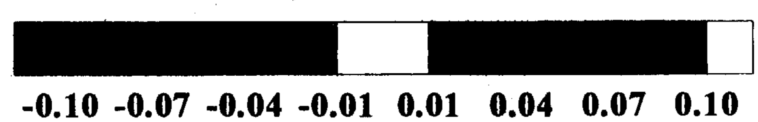
$= 10.0\ m^{-1}$

$N_s = 800$

$N_c = 1400$



Re[Instantaneous Acoustic Pressure]



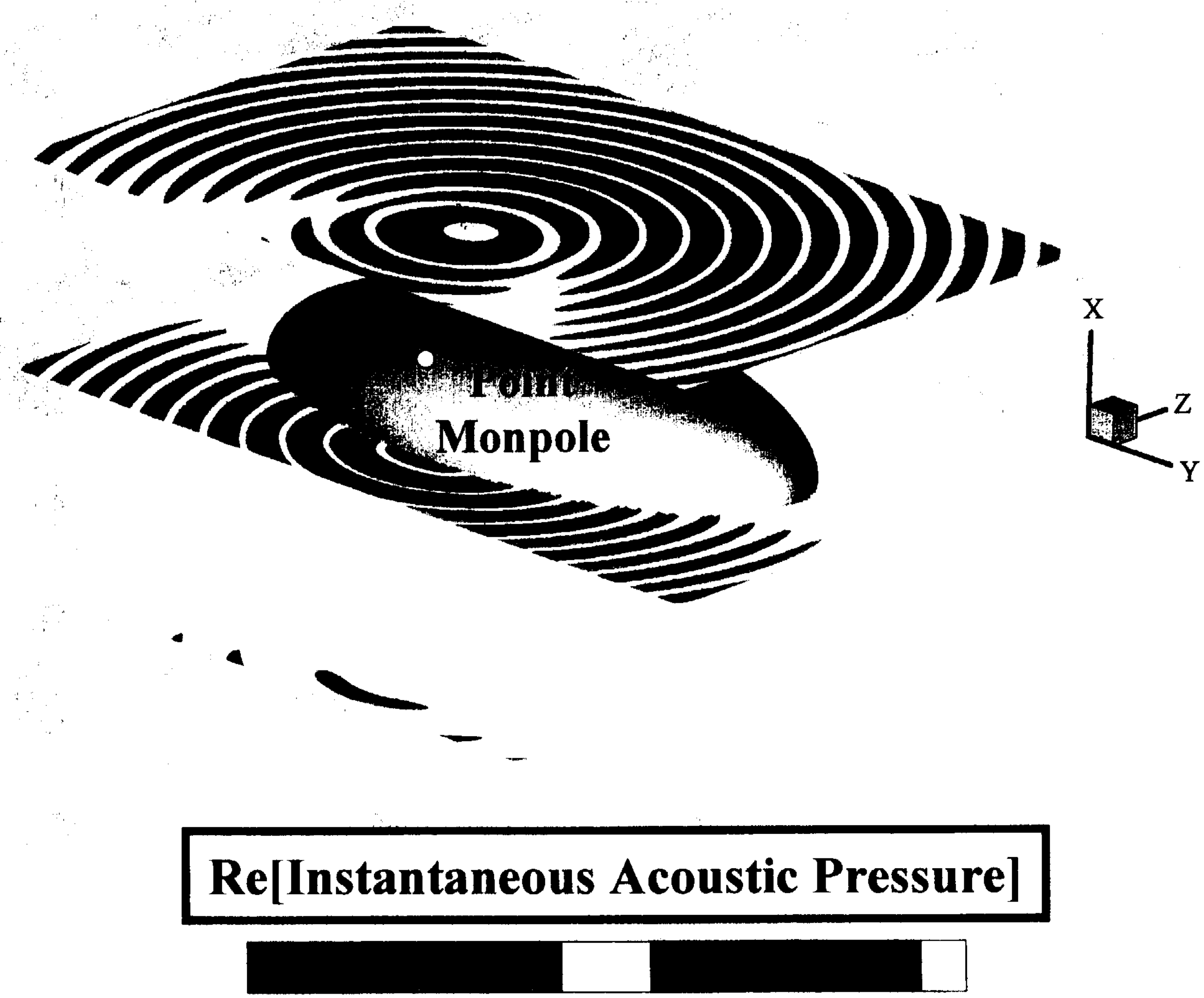
3-D Scattering Results
(y-z slices)

$k = \omega/c$

$= 10.0\ m^{-1}$

$N_s = 800$

$N_c = 1400$



Conclusions

- The 2-D version of the ESM was successfully upgraded to include a simple 3-D scattering problem.
- Rapid, 3-D, ESM noise predictions using PC's are attainable. Scattering results appear to be physically correct.
- The ESM is sensitive to the number and location of source and collocation points.
- Numerical experimentation with this problem has provided guidance for conducting the final phases of this research project.

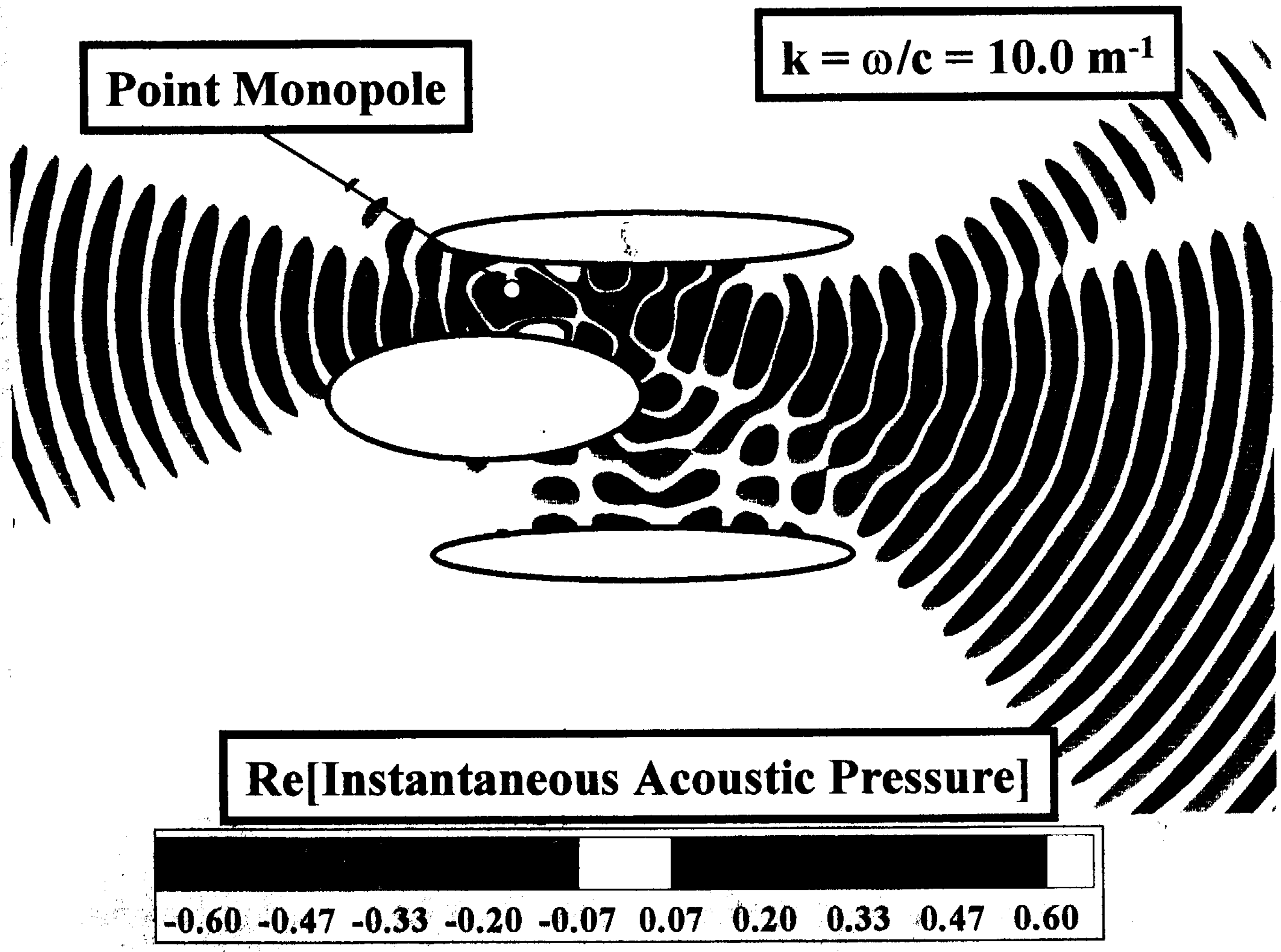
Future Effort

- The next step is to link the 3-D ESM code with TBIEM3D so as to replace point source generated incident sound with ducted fan input. TBIEM3D has been modified for this purpose.
- The final phase will be to replace the ellipsoid with blended wing geometry.
- Estimated Completion Date: 09/30/1999.

Future, Future Effort (should interest in this subject resurface)

- **Due to the simplicity and ease of implementation of the ESM, it appears to be a promising noise prediction technique that can be applied to other aeroacoustic scattering problems. For example the current work can be expanded to include uniform inflow effects and sound absorbing surfaces. Also, as demonstrated by the 2-D ESM, multi-component geometries can be incorporated.**

2-D Multi-Component Scattering



More Future, Future Effort

- The ESM approach to noise prediction can be enhanced considerably by a detailed theoretical study of the mathematical foundation. The literature on this subject is relatively sparse. For example, the location and type(s) of equivalent sources could be optimized for more accurate and faster predictions. Also, the use of multi-pole expansions and/or simple surface distributions of equivalent sources may prove promising.

Attachment 2: Application of the Equivalent Source Method to the Scattering of Ducted Fan Engine Noise by a Blended Wing-Body

Application of the Equivalent Source Method to the Scattering of Ducted Fan Engine Noise by a Blended Wing-Body

A Mini-Presentation for the
4th AST Engine/Nacelle Noise Workshop
November 17, 1999

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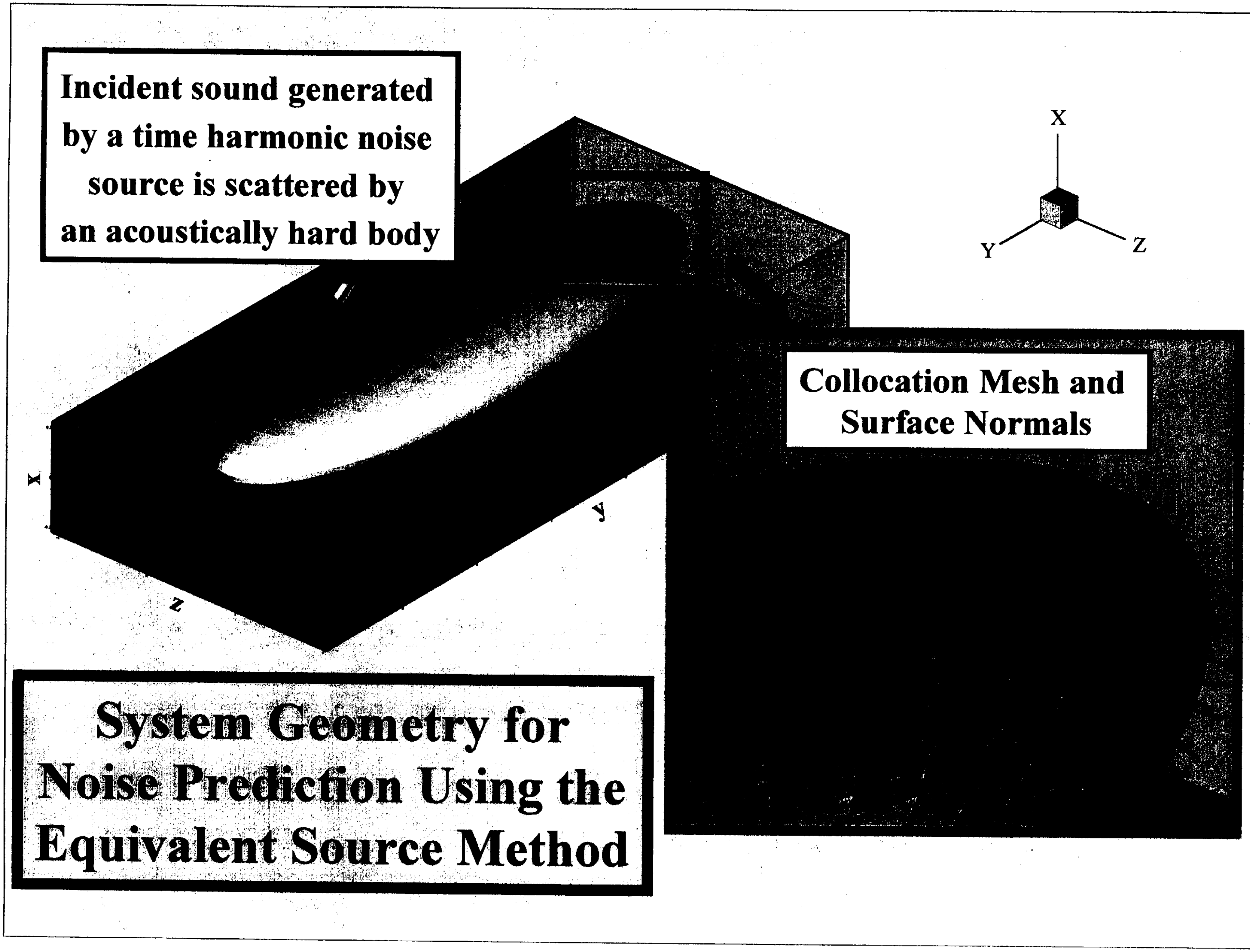
Old Dominion University

Research Grant Sponsored by NASA Langley

Outline

- Description of the Equivalent Source Method (ESM)
- 3-D Noise Predictions for Model Blended Wing-Body (BWB) and Ducted Fan Configuration
- Conclusions


Incident sound generated by a time harmonic noise source is scattered by an acoustically hard body
X
Y
Z
x
y
z
Collocation Mesh and Surface Normals
System Geometry for Noise Prediction Using the Equivalent Source Method

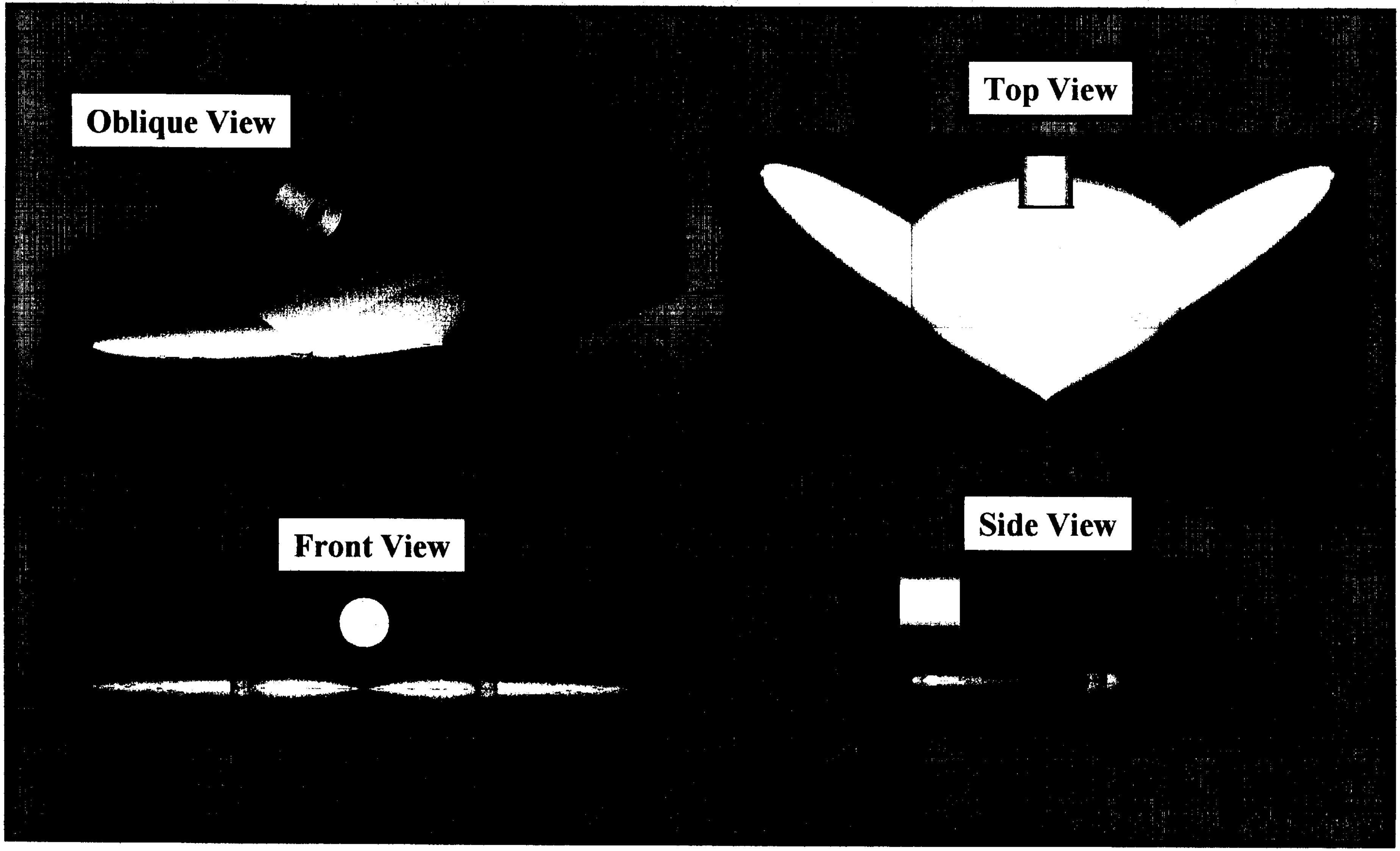
The Equivalent Source Method

- The ESM replaces a complex surface distribution of acoustic sources with a collection of simple “equivalent sources” placed inside the scatterer. Source strengths are chosen to satisfy the acoustic boundary condition on the scatterer’s exterior surface. We consider only the hardwall BC and no inflow in this work.

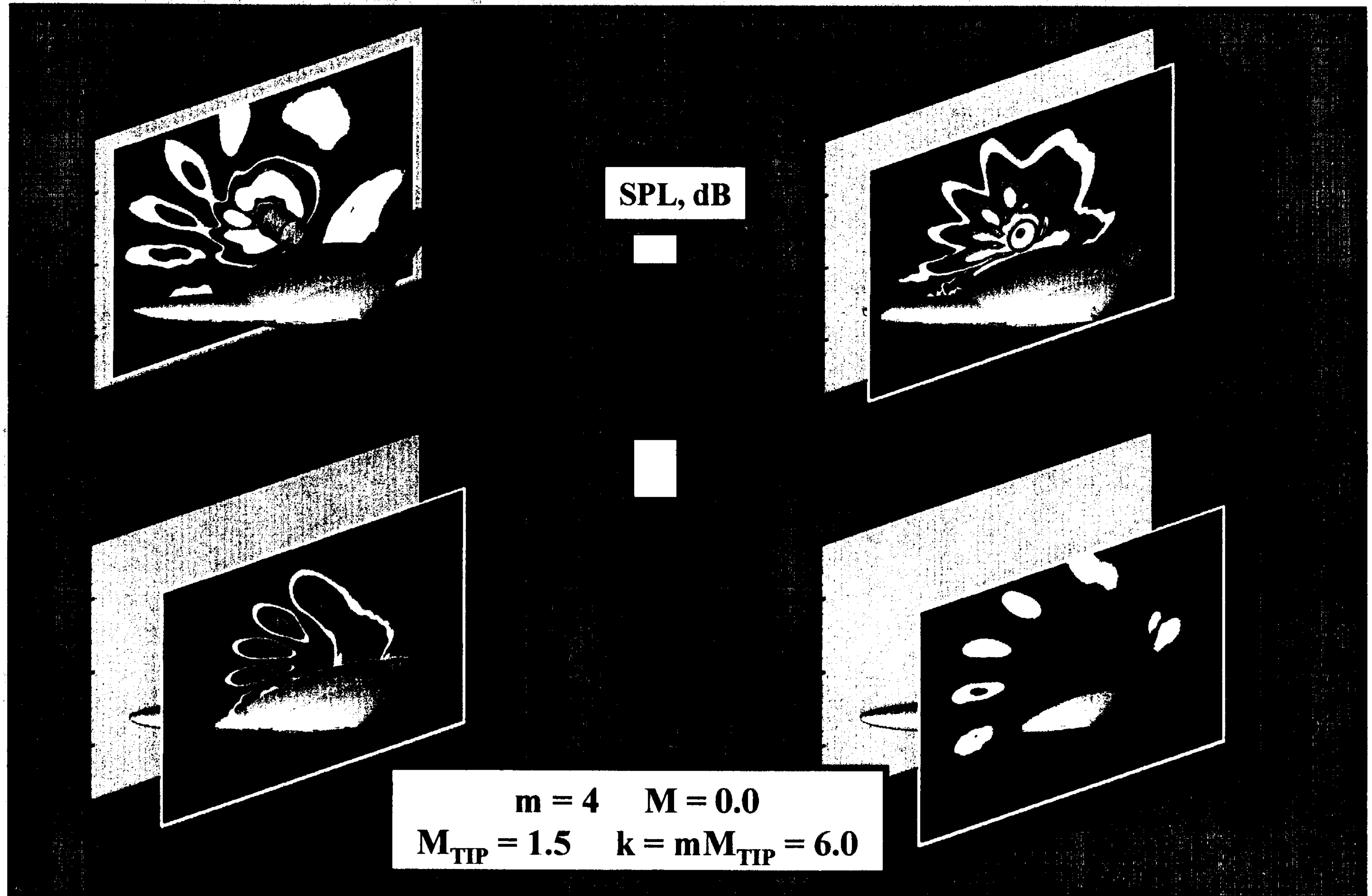
- Compared to more conventional prediction methods, such as those that use boundary integrals or boundary elements, the ESM is much simpler to implement and calculate.

Noise Prediction Results - Scattering of Ducted Fan Engine Noise by a Blended Wing-Body Configuration

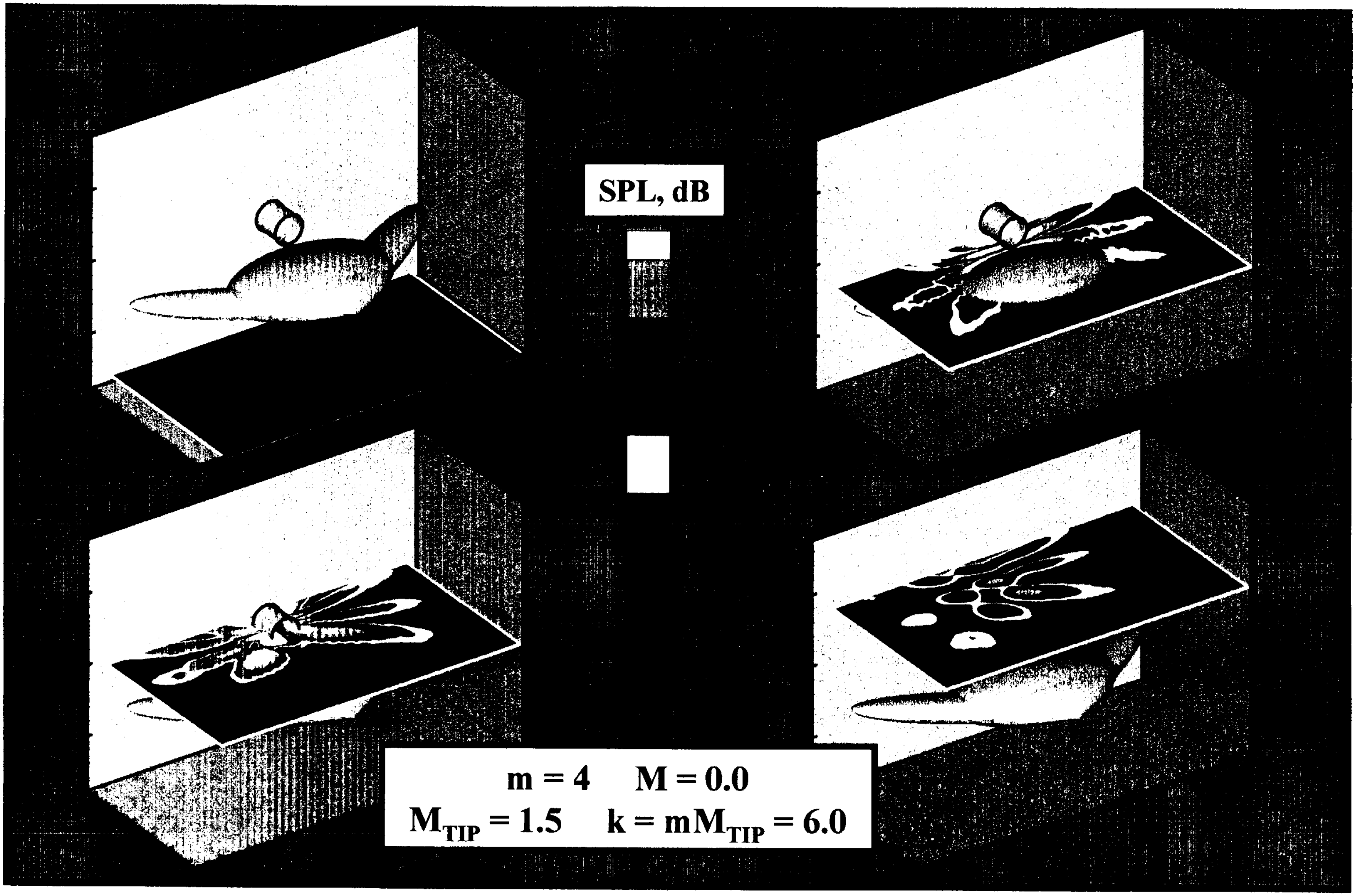
- **BWB geometry based on Langley experimental model. Ratio of BWB width to duct radius = $W_D = 20$.**
- **Fan noise is modeled by four spinning point axial dipoles which generate the $m = 4$ circumferential mode. The fan rotational speed is such that one radial mode is cut-on.**
- **TBIEM3D used to predict radiated engine noise and supply input to ESM.**
- **Comparisons with experimental results are pending.**



Blended Wing-Body and Ducted Fan Geometry



3-D Scattering Results - Axial Planes of Sound Pressure Level



3-D Scattering Results - Horizontal Planes of Sound Pressure Level

Conclusions

- **Due to observed shadow regions in SPL field, scattering results appear to be physically correct.**
- **Rapid, 3-D ESM noise predictions using PC's are attainable for values of the dimensionless quantity $kW_D < 200$.**
- **The ESM is sensitive to the number and location of source and collocation points.**
- **ESM algorithms are well suited for multi-processor computing.**